

Case Study of US 75: Assessment of Full Depth Repair Effectiveness

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Abstract

Full depth repair (FDR) is a widely used repair method for repairing distresses in concrete pavement. FDR typically includes restoring load transfer to the adjacent, unrepaired slab and once it is placed is expected to perform similarly to the original pavement. However, current standard methods of FDR have only limited effect and often yield insufficient long term performance since they fail to address the deterioration ongoing in the adjacent slabs. It seems that standard plans uniformly recommend replacing weakened base or subgrade material with better material however, they only treat the area under the patched section, while the condition of adjacent sections continue to suffer because of the effects of infiltrated water and weakened base and subgrade. Moreover, details rarely call for resealing of the joint after placement of the repair which is a basic preventative strategy to reduce distresses in the adjacent concrete pavement as well as the patch. A major test of FDR for jointed concrete pavement on US 75 in Sherman, Texas is studied to evaluate FDR effectiveness and recommend possible improvements. Sample sections were classified by visual inspection into good and poor areas containing old and newly placed patches. Each section was tested to ascertain the repaired patched and existing adjacent pavement conditions using non destructive test (NDT).

Introduction

Full depth repairs involve replacing a portion of slab with new concrete. When other maintenance repair methods are not appropriate, full depth repair must be employed. When repair boundaries are decided, sawcuts delineate where the old concrete is to be removed before placing with new concrete. Each repair is supposedly large enough to minimize future problems in the adjacent slabs. Patching width is normally the same as the lane width but often half a lane width is recommended.

Figure 1a shows the patching patterns and general idea of the transverse and longitudinal joint type in jointed concrete (JC) pavement repair configurations (ACPA 1995). Figure 1b shows full depth repair detail used by the Texas Department of

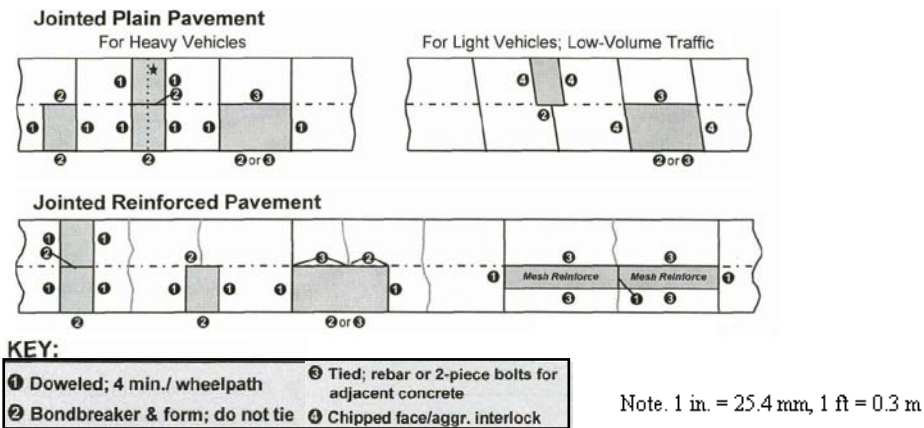
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Transportation (DOT) (TxDOT 1998). This standard plan recommends tiebars or dowel size and spacing for the various concrete types and thicknesses in the table. Many state DOT's standard plans recommend replacing weakened base or subgrade material with similar or better material, and some states recommend a thicker concrete slab to fill any material removed. Otherwise, these techniques only treat the area under the patched section, while the adjacent section continues to suffer because of the infiltrated water and weakened base and subgrade. Moreover, details rarely call for resealing of the joint after placement of the repair.



1-a) Full Depth Repair Layouts and Joint Types (ACPA 1995)

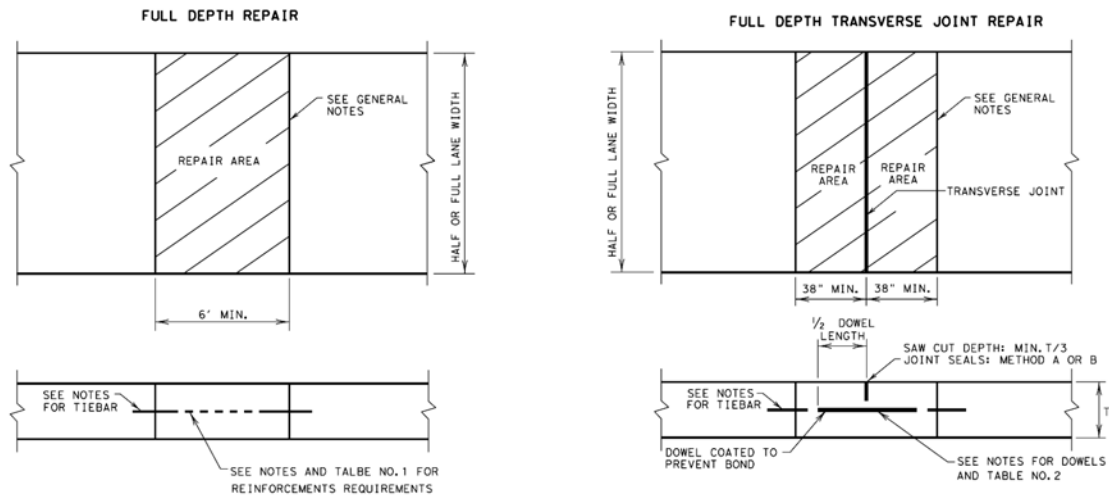


TABLE NO. 1 STEEL BARS SIZE AND SPACING						
TYPE OF REINFORCEMENTS	TYPE PAVEMENT	PAVEMENT THICKNESS (INCHES)	TIEBARS		REGULAR REBARS	
			SIZE BAR (BAR NO.)	BAR SPACING (INCHES)	SIZE BAR (BAR NO.)	SPACING (INCHES)
TRANSVERSE BARS	CRCP	ALL	#6	24	#6	24
	JCP (CPCD)	ALL	#6	24	NONE	NONE
LONGITUDINAL BARS	CRCP	8	#6	9	#6	9
		9	#6	8	#6	8
		10	#6	7	#6	7
		11	#6	6.5	#6	6.5
		≥ 12	#6	6	#6	6
	JRCP	ALL	#6	12	#6	24
	JCP (CPCD)	ALL	#6	12	NONE	NONE

TABLE NO. 2 DOWELS (SMOOTH BARS)			
PAVEMENT THICKNESS (INCHES)	SIZE AND DIA.	LENGTH (INCHES)	SPACING (INCHES)
8	#8 (1 IN.)	18	12
9	#9 (1 1/8 IN.)		
≥ 10	#10 (1 1/4 IN.)		

Note. 1 in. = 25.4 mm, 1 ft = 0.3 m

1-b) Full Depth Repair for Concrete Pavement (TxDOT 1998)

Figure 1 Full Depth Repairs.

Research Significance and Objectives

This paper reports on the development of a set of guidelines to identify characteristics common to poor performing FDR, identification of and guidelines for test methods to rate repair efficiency in the field, evaluation of methods for classifying conditions of FDR (using NDT testing and slab coring), and recommendation of possible improvements to FDR methods.

Current Performance and Construction Issues on US 75

Sections of US 75 that were selected for sampling purposes were jointed at 4.5 m intervals and built in 1983. Traffic information was limited but was found to be 42,760 ADT in 1997. Much of the jointed pavement over the sampled areas has exhibited poor performance since the early 1990s. Shattered and settled slab conditions were prevalent and worsening with time because of pumping and poor drainage contributing to erosion of the base and weakening of the subgrade (Figure 2). The good performing areas however, showed no distress particularly where the shoulder joint seals were kept in good condition. Well maintained joint seals seem to be effective blocking surface water from intruding into the pavement section. The same characterizes were evident in the good performing patched areas as well. The shoulder joint seals in the poor performing sections typically showed significant joint seal deterioration ultimately leading to base and subgrade erosion damage.

Joint repairs were performed in 1996 and then a major rehabilitation involving slab jacking using polyurethane material was undertaken in 2004 to fill voids under the slab and eliminate eroded areas below the affected slabs due to pumping action. After the repair, generally, very little settlement was observed for the first two years, however, some slabs started to crack and pavement conditions soon worsened. This problem could possibly have been caused by inadequate undersealing and a saturated base and subgrade conditions by damaged joint seals. Performance observations indicated a greater incidence of corner cracking after the undersealing work shown in Figure 2. Note the cracks formed between these holes and the transverse joint or shoulder.

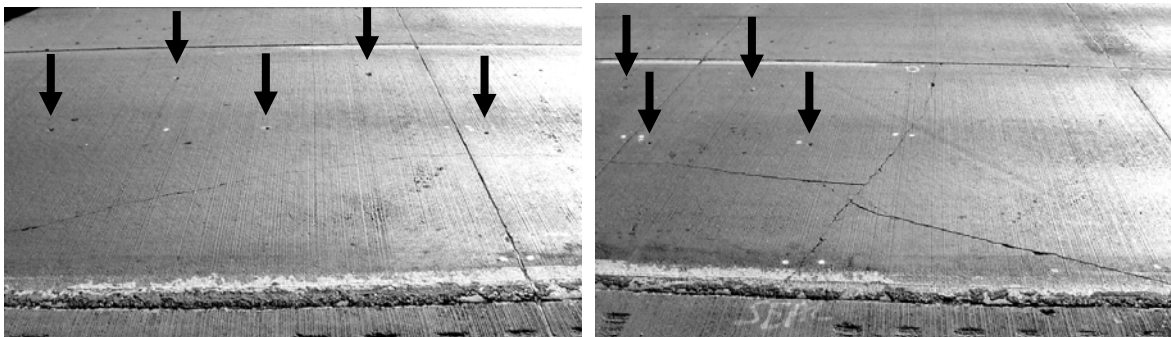
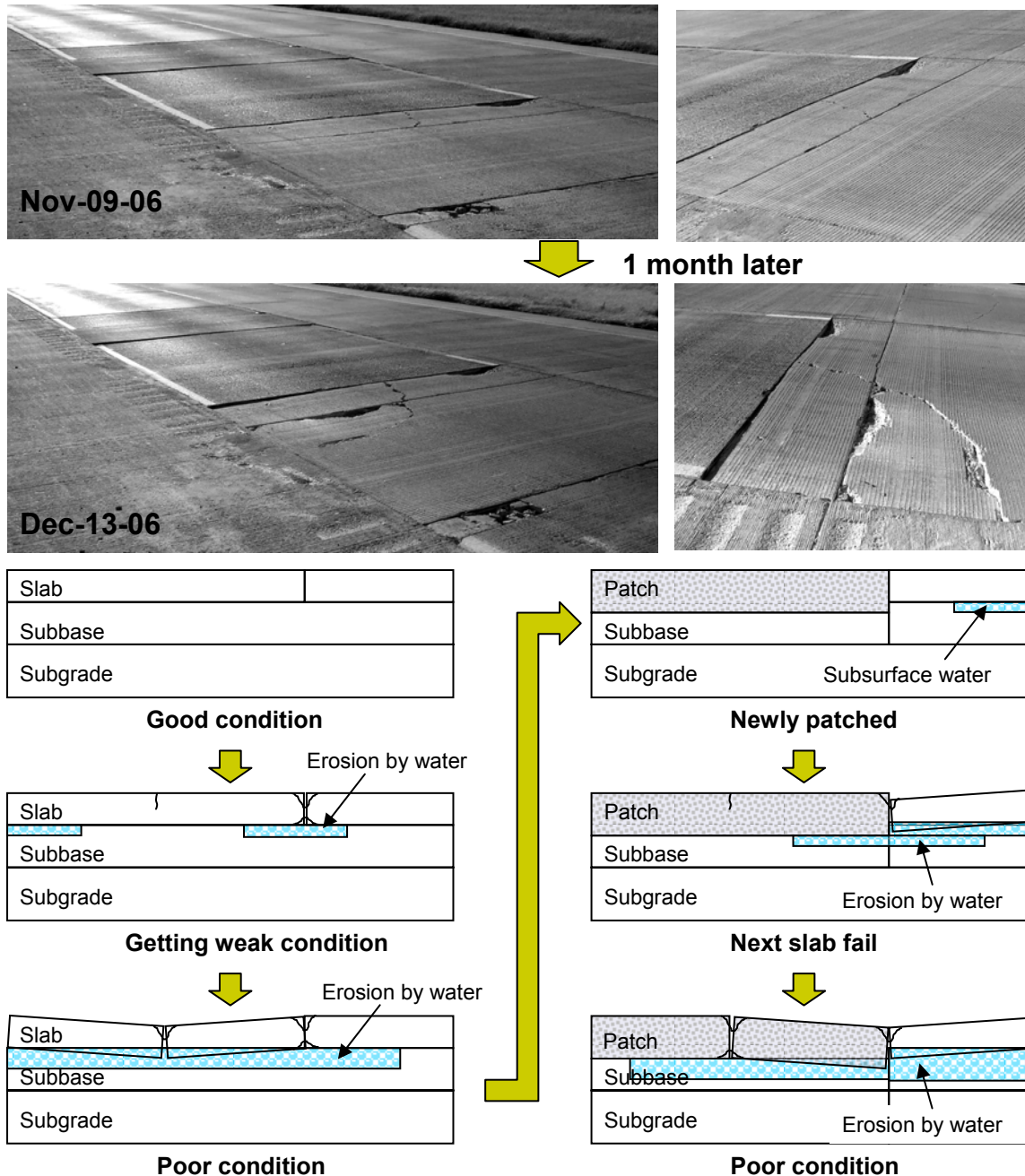


Figure 2 Locations of Slab Jacking Holes and Cracks on Slabs in Poor Condition.

FDR was employed as another method to eliminate badly deteriorated sections. However, FDR's or the adjacent areas occasionally fail soon after placement perhaps

because of saturated and weakened base and subgrade materials. Adjacent slab damage was often caused by the FDR itself or because moisture was able to readily penetrate the subgrade below the FDR.

Damaged joint seals (especially along the shoulder joint) often allow for the penetration of water in the joint which can be problematic particularly if it is not removed prior to resealing of the joint. Figure 3 shows the pictures how quickly patching areas deteriorate especially with intrusion of water due to a lack of joint sealing. Moreover, rocking of the slab caused by insufficient load transfer efficiency (LTE) and poor base/subgrade compaction resulted in significant faulting within the patch sections.



Evaluation of Full Depth Repair Effectiveness

A combination of a NDT and coring were used to evaluate the effectiveness of FDR sections and the condition of the adjacent JC pavement. The section profile was 25 cm thick over 15 cm of an unbound aggregate base and a natural weathered soil subgrade. There was a combination of both cracked and uncracked sections but overall, the drainage condition appeared visually to be poor since there was a significant amount of standing water present in the borrow ditches alongside the sample sections.

Falling Weight Deflectometer (FWD) Testing. FWD testing is commonly employed to aid in the determination of overall structural capacity in terms of slab stiffness, loss of support (voids), LTE of the joint, and basin area. Although back calculation analysis involves theoretical related assumptions, FWD test procedures are well established and simple to apply for investigation of pavement conditions (Zollinger et al. 2003). Since LTE is integral to the stiffness of a joint, determining when load transfer retrofitting should be considered could be based on LTE being lower than a certain amount a substantial amount of time. Deflection basin area is a simple means to detect possible deteriorated areas. The locations which show low deflection basin areas could be interpreted as problematic indicating areas of low stiffness. The typical range of basin area for 25 cm thick rigid highway pavements is between 60 and 85 cm, and load transfer retrofitting may be recommended when basin areas are lower than 60 cm. LTE and basin area were back calculated using equations 1 and 2 from FWD data to evaluate relative pavement stiffness.

$$LTE = \frac{d_U}{d_L} \times 100 \quad (1)$$

Where, LTE = Load transfer effectiveness,

d_U = Deflection on the unloaded side of the joint or crack, and

d_L = Deflection at the loaded side of the joint or crack.

$$\text{Basin area} = \frac{6(D_0 + 2D_1 + 2D_2 + D_3)}{D_0} \quad (2)$$

Where, Basin area = FWD deflection parameter,

D_0 = Deflection at the loading position,

D_1 = Deflection at 30 cm from the loading position,

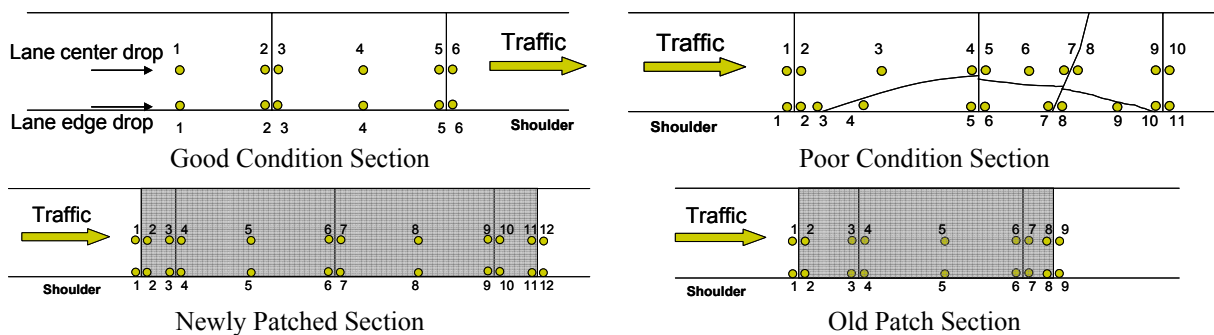
D_2 = Deflection at 60 cm from the loading position, and

D_3 = Deflection at 90 cm from the loading position.

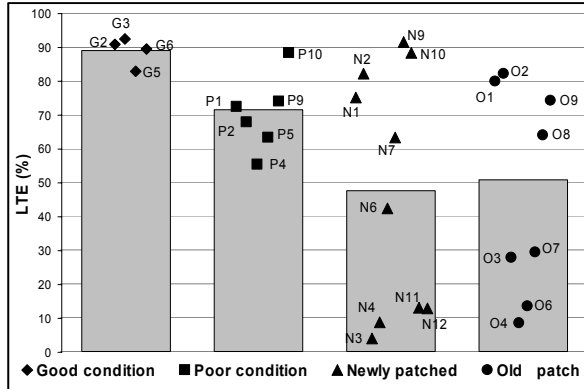
Test locations consisted of testing before and after the joint and at the mid slab location. These locations were tested along the edge, in the wheel paths, and at the center of the slab. Figure 4a illustrates FWD testing locations. Figures 4b and 4c are bar charts showing joint LTE at the center and the edge of slab over a range of pavement conditions. Unexpectedly, the poor condition section had the highest LTE along the slab edge, while the newly patched section had the lowest LTE (which was less than 40 %). Two out of five test locations associated with new patches had good LTE (approximately 80 % and

the newly patched section had the lowest LTE (which was less than 40 %). Two out of five test locations associated with new patches had good LTE (approximately 80 % and 90 %) while the other three joints had poor LTE (approximately 50 %, 10 %, and 7 %). The older patch sections providing better performance than the new patch sections had also low load transfer (approximately 50 % to 60 %). The test data suggests the reason for the failure of the FDR shown in Figure 3 was low LTE and a degraded base support condition.

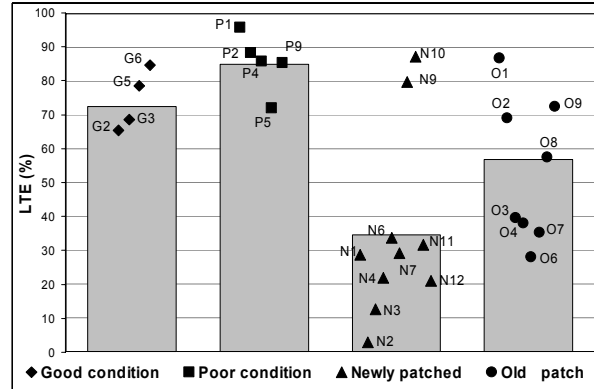
Figure 4d shows the mean and standard deviation of FWD basin areas. Patched sections showed a lower mean basin area with a higher standard deviation than the cracked poor performing areas, which means the general structural capacity of FDR was lower than even the problematic pavement areas manifesting non-uniform support and premature slab shattering.



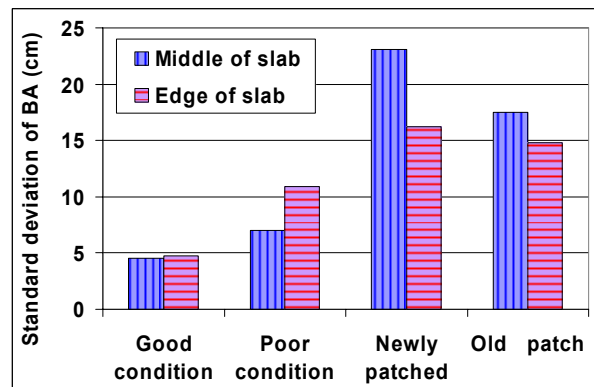
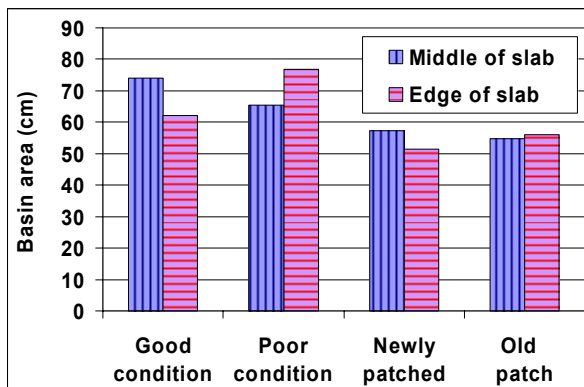
a) Test Sections and FWD Location ID Numbers



b) Joint LTE of Lane Center Drop



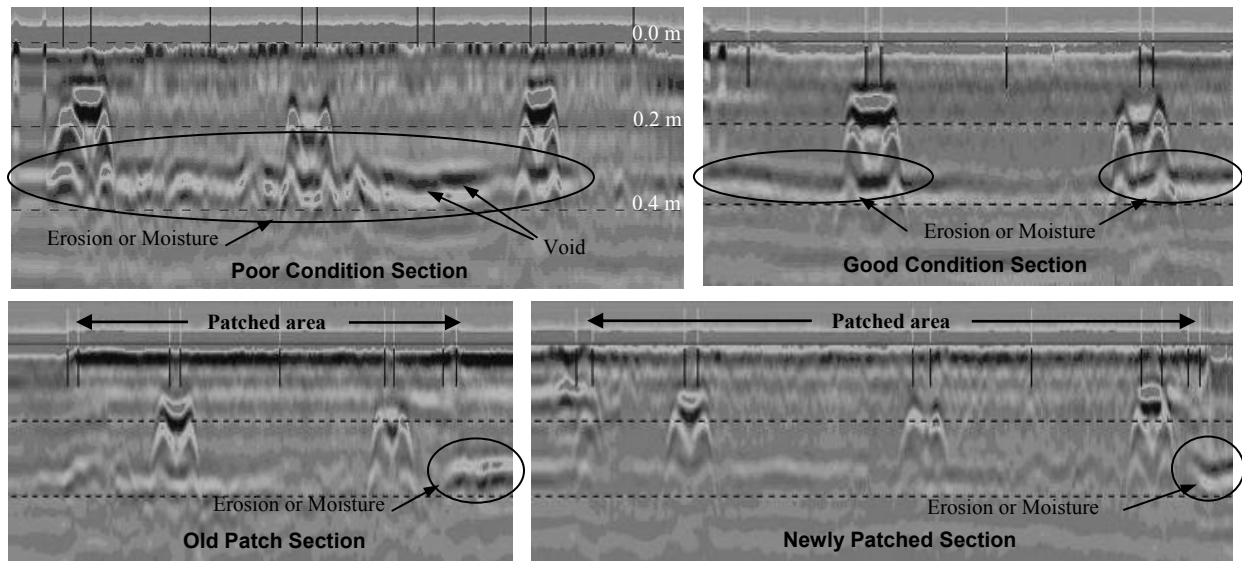
c) Joint LTE of Lane Edge Drop



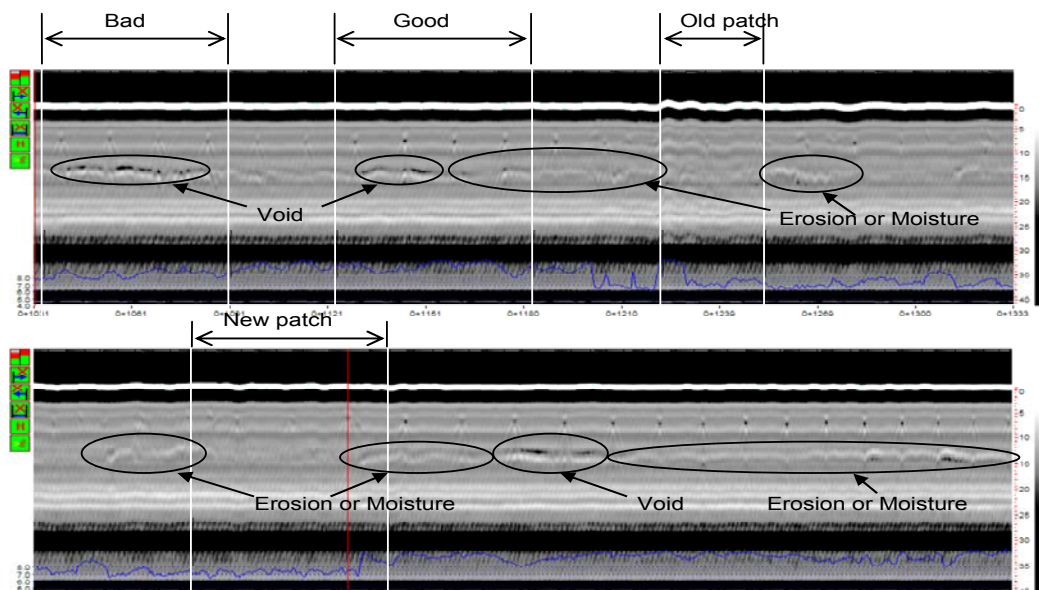
d) Mean and Standard Deviation of Basin Area

Figure 4 FWD Testing Result Analysis.

Ground Penetrating Radar (GPR) Testing. GPR testing appears a fast and effective test method to determine base conditions such as voids and the presence of water trapped in the layers (Zollinger et al. 2003). Figure 5 shows GPR images which represent voids as black areas and eroded or wet areas as a bright zone. Poor performing sections showed many voids and wet areas while the good performing sections showed some areas with erosion and moisture. The patched areas did not show significant moisture damage, but adjoining areas showed the presence of water which could affect the adjacent patched area in the future as previously noted in Figure 3. The line at the bottom in Figure 5b indicates the surface dielectric value which indicates the moisture level of the subgrade. The test data tends to suggest when a DC value of the concrete surface is higher than 9, a wet subgrade condition below the subbase may exist.



a) GPR along FWD Lane Center Drop Points



b) GPR along Edge Side Wheel Path

Figure 5 GPR Image Analysis.

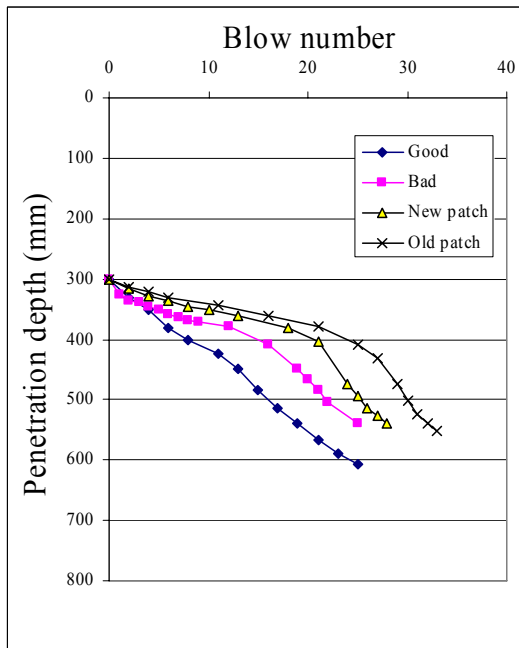
Dynamic Cone Penetrometer (DCP) Testing. DCP testing is useful to indicate the in-situ strength of the base and subgrade soils. The test provides a correlation between the strength of the soil and its resistance to penetration (Zollinger et al. 2003). It is fast and easy method and can be used to estimate the elastic modulus of each layer and sublayer. Equation 3 shows the relationship between the penetration ratio and elastic modulus of soils in Texas (Chen et al. 2005).

$$E = 538,155 \times PR^{-0.6645} \text{ (kPa)} \quad (3)$$

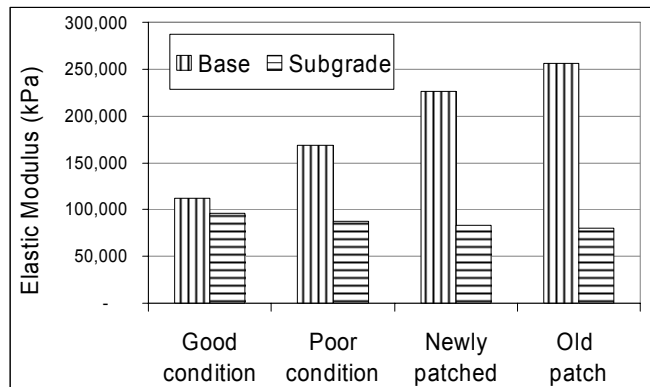
PR = Penetration ratio (mm/blow)

The base type for all sections investigated was an unbounded aggregate base where the estimated elastic moduli appeared to be quite low as shown in Figure 6. The base in the good performing areas had nearly the same modulus as that of the subgrade and there appeared to be a significant loss of base strength in the unrepaired areas; typical elastic modulus for an unbounded aggregate base ranges from 100 to 300 MPa (Huang 2004).

The patched areas showed relatively higher modulus than the unrepaired sections for the base layer but no significant difference for the subgrade layer. The low modulus for the subgrade seemed to indicate that a wet condition was prevalent which seemed to correlate with the presence of standing water along the shoulder joint strongly suggesting the possibility of poor surface drainage. The accumulation of surface water most likely contributed to the degradation of the base and subgrade modulus particularly where the longitudinal joint seal was damaged and weathered.



a) Penetration vs. Blow Number



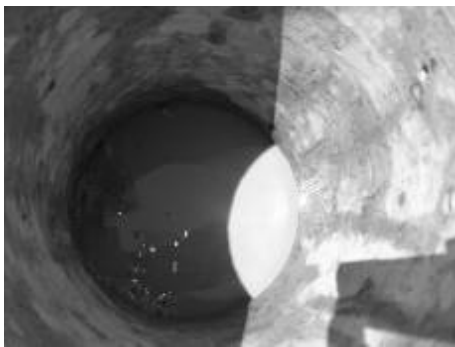
Layer	Elastic modulus (kPa)			
	Good condition	Poor condition	Newly patched	Old patch
Base	112,096	168,316	226,226	255,754
Subgrade	95,928	87,155	83,568	80,140

b) Elastic modulus vs. depth and pavement conditions

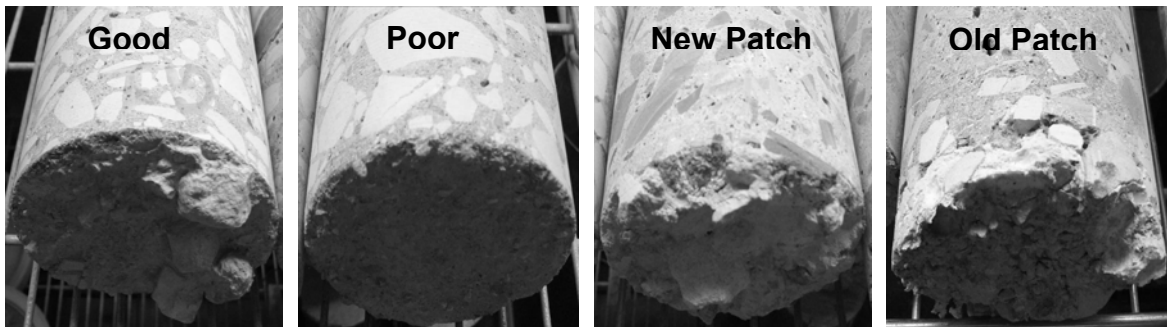
Figure 6 DCP Testing Results.

Coring Samples. Core samples were taken as a means to measure the compressive strength of the concrete and to indirectly estimate the modulus of the concrete layer. The core hole also provided for a means of visual observation of voids and eroded base areas (Zollinger et al. 2003). Figure 7a shows a core hole located in a poor performing section exposing a voided area of the base material due to erosion.

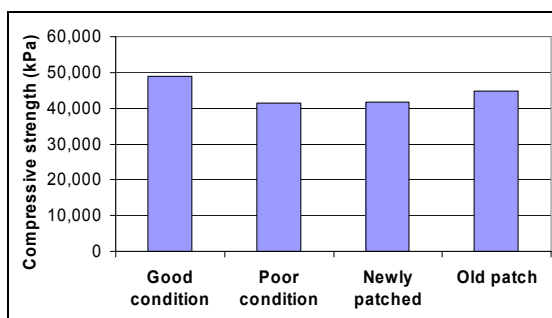
Figure 7b shows the bottom surface of a core indicating the condition of the bond between the concrete and base. The core sample from the poor condition section showed evidence of separation (caused by erosion and pumping action) while the sample from the good condition section showed partial debonding between the concrete slab and base. Cores from patched areas did not show any evidence of separation. Concrete strength test results, shown in Figure 7c, indicate that the concrete material was sound and there was no evidence of weakened concrete.



a) Void and Erosion Under the Concrete Slab of Poor Condition Section



b) Top and Bottom Surface of the Cores



c) Compressive and Tensile Strength of Concrete Slabs

Figure 7 Findings from Sample Coring and Strength of Cores.

Recommendations for Effective Repairs

Based on the pavement condition evaluation, the following decision flowchart provides the guidance for effective FDR and the repair of adjacent JC pavement. The decision flowchart in Figure 8 is self explanatory and with these evaluation tools, appropriate repairs could prolong the life of existing patch areas or improvement of FDR installation.

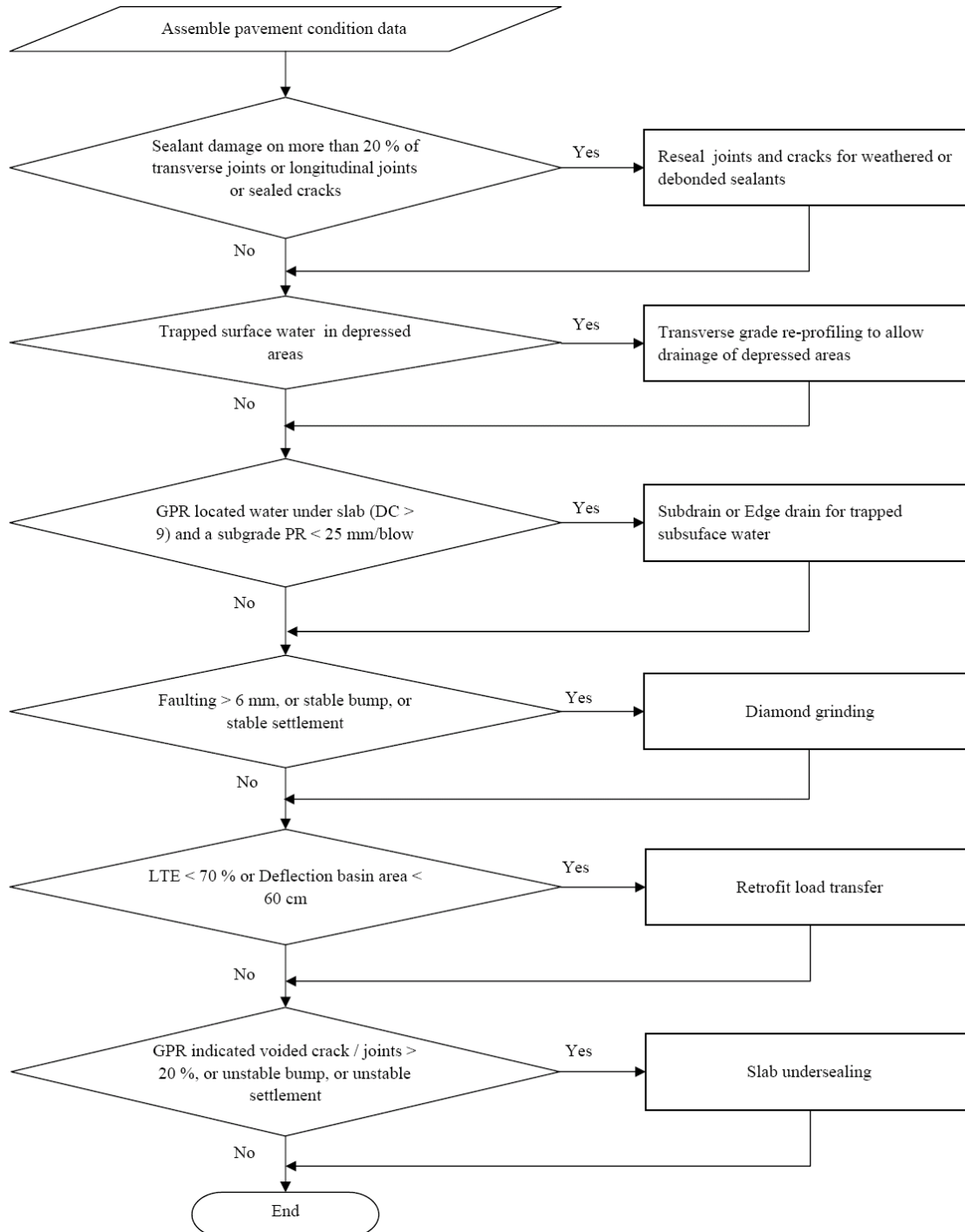


Figure 8 JC Pavement Repair Decision Flowchart.

Joint Sealing. Joint sealing is a basic strategy that can reduce the development of significant distresses in the adjacent concrete pavement as well as the patch. Although joint sealing may not only minimize water infiltration the decrease in the potential for a weakened base and subgrade under pumping action can have a significant effect on performance life. The longitudinal joint is particularly important to maintain since extensive amounts of surface water can enter at that location. Crack sealing is recommended when crack width is wider than 0.75 mm and resealing joints and cracks is recommended when sealants are damaged over more than 20 % along the joint or crack. Selection of proper sealing material should be based on temperature and moisture conditions; trapped subsurface water should be removed before re-sealing operations to prevent premature failure of the joint.

FDR Subbase and Base Preparation. After the old concrete material has been removed, the base course should be examined and any disturbed material removed and recompact before placement of the patch. Replacing some or all disturbed base material (or material shown to have a modulus is less than 70 MPa based on DCP test results) with concrete or flowable fill may be the best alternative if it is difficult to adequately compact granular material inside the patched area. If proper compaction is not achieved, the base could settle and a void develop under the slab. If excessive moisture exists in the repair area, it should be removed or dried before replacing.

Subdrain or Edge Drain System. When the dielectric constant of the existing patch to be replaced is higher than 9 using GPR, inadequate drainage may exist and base and subgrade integrity may be an issue. Retrofitting of a drainage system may be needed to mitigate weakened subgrade areas. However, edge drainage is not recommended if the base is unstabilized and contains more than 15 % of fines (passing No. 200 sieve), or the pavement structure is simply undrainable. As mentioned earlier, some or all disturbed base material in a repair situation should be replaced with concrete or a flowable fill of 6,900 kPa or greater. Figure 9 shows the applicable drainage system details used by Iowa DOT; a 7.5 cm slotted corrugated pipe or longitudinal subdrain is employed for FDR granular subbase. (Iowa DOT 2007).

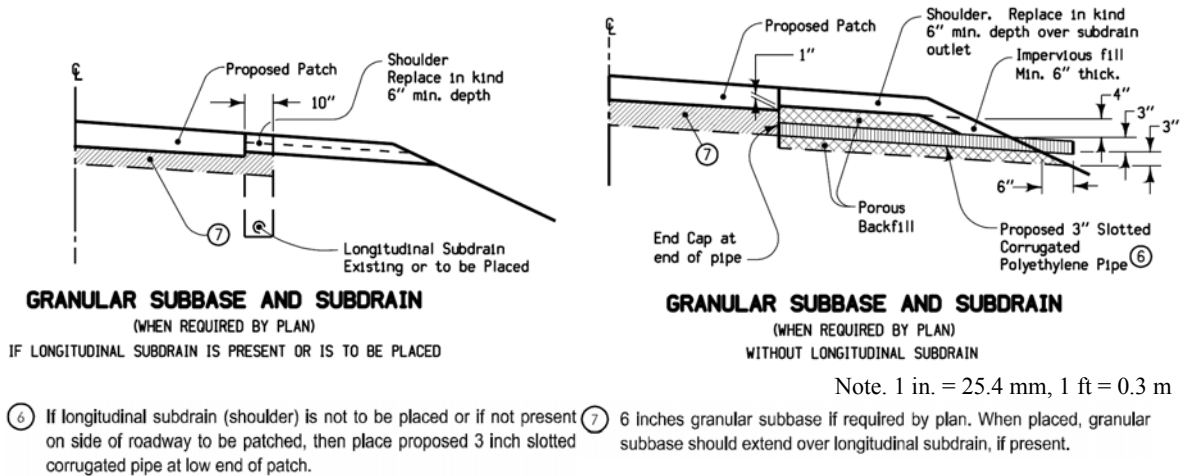


Figure 9 JC Pavement Repair Decision Flowchart.

Smooth surface profile. Following up FDR with grinding is sometimes necessary to remove resulting uneven surfaces which may affect ride quality and service life by creating an impact load condition at the joint. Moreover, when patches are more than ten per mile and faulting more than 6 mm, diamond grinding is suggested to provide a smooth riding surface with good texture and noise reduction for 3 to 5 year period. When stable bumps or settled areas are present, diamond grinding can also be effective.

Restore Load Transfer. When a pavement shows spalling, faulting, low stiffness, or pumping at joints or transverse cracks, the load transfer efficiency could be diminished due to repeated heavy loads. When the LTE at the joint is lower than 70 %, the basin area is less than 60 cm, or joints are spalled more than 5 cm wide over more than 20 % of the joint or crack, load transfer retrofitting (with slab stabilization if voids are detected) in the wheel path is recommended with approximately 6 dowel per lane.

Slab Stabilization. Slab stabilization (or slab undersealing) could be used as a maintenance repair method when current patch or adjacent pavements have voids below them. Slab undersealing is recommended when GPR indicated voided crack or joints are more than 20 % of inspected section or where unstable bump or unstable settlement are present. The injected material ideally should displace water from the voids and fill the vacated space without raising the slab. During the injection process, any upward movement of the slab needs to be detected to ensure that the slab is not raised. Faulting between two slabs could be eliminated using grinding after slab stabilization. The most common injection hole pattern is in the wheel path and sufficient holes are needed to permit grout to reach all voids beneath the pavement. Experienced contractors and proper inspection are essential to properly identify and underseal damaged areas. GPR can also be used to optimally locate holes to ensure good grout distribution and void filling.

Conclusions

Non-destructive testing and coring were used to evaluate the effectiveness of FDR sections and adjacent JC pavement condition on US 75 near Sherman, Texas. Overall FDR effectiveness of both new and old patches was low. The drainage conditions were generally poor and standing water existed alongside the pavement shoulder joint. LTE was low at the slab/patch joints and base and subgrade moduli require stabilization to reduce early failure of patches and adjoining slabs. NDT results are summarized as follows:

- LTEs of FDR for new and old patches were variable and on the average low. Old patches have significantly lower LTE at the transverse joints which were doweled.
- Patched areas did not show significant erosion damage, but in many instances, water was presented under the adjoining areas which could eventually migrate into the patch areas and weaken the subgrade.
- Concrete strength test results showed no evidence of a concrete strength related problems.

- Patching areas showed good moduli values for base but low moduli for the subgrade.

Improved FDR performance and specifications may entail base and subgrade replacement, subdrainage or use of an edge drainage system, follow up diamond grinding, and joint sealing to assure a high level of performance; while existing patches and adjacent slabs should be checked by NDT as part of a long term maintenance program incorporating load transfer restoration, slab stabilization, and joint resealing to prolong pavement service life.

Acknowledgments

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